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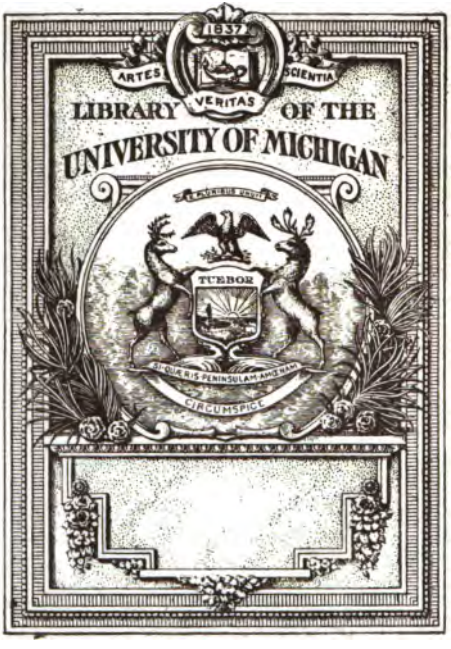
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THE

VENTILATION

OF

COAL MINES.

BY

W. FAIRLEY, M.E., F.S.S.

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PREFACE.

The object of the following articles is to give to the practical miner as clear an idea as possible of the general principles of mine ventilation. The subject is one of the most important that can engage the attention of the mining engineer, and is one that should be well understood by all who are engaged underground. It is to be feared that this is far from being the case—that great ignorance still prevails in mining quarters on the subject, and that there is much need of a dissemination of information on the art of ventilating engineering.

The fact that 586 lives were lost in 1880 by explosions of fire damp emphasizes the remarks of the writer as to the

importance of the question, and a consideration of the circumstances under which some of those explosions occurred force upon him the opinion that much has yet to be learned by many officials who are treated as competent.

Every ordinary miner should have a knowledge of the subject, because—in fiery mines especially—the safety of the whole number depends upon the individual action of each man employed.

The writer has attempted to explain as much as possible, by the working out of examples arithmetically, the various principles taken into consideration.

To those who are masters of the subject, some of the explanations given may be considered unnecessary; his reply to this is, he has not written for them, but for those who do not understand it; and, for the sake of those practical men who are anxious to grapple with the question,

he has treated it as much as possible according to the simple rules of arithmetic. The most that will be required of the student in working out the examples given is a practical acquaintance with the manner of extracting square and cube roots.

The cause of motion in air has been explained in the first section, where it has been shown arithmetically that pressure may be expressed either by feet of air column, inches of water gauge, or pounds per square foot.

The friction of air has then been dealt with, and several new formulæ have been given, which will be found useful in working out practical examples.

An explanation of splitting has been entered into, and the difference between equal and unequal splitting has been explained.

Ascensional ventilation is a matter

which deserves the attention of all mining engineers, and no doubt a proper knowledge of this art would enable ventilating engineering to be conducted practically in a much better and far more economical manner than it usually is.

Next, it has been considered necessary to draw particular attention to *Velocity*, and to endeavor to fix some medium as the speed at which air should travel. Many practical men think the pit is well aired if the current is traveling at a high speed, but there is a medium in this as in other things.

The co-efficient of friction, referred to especially, depends on the nature of the sides of the channel through which the air passes, and even in the same pit the co-efficient may be different according to the rubbing surfaces of the roads; the smoother the sides the less the friction, and roads formed with brick work have

only about one-half the friction of ordinary underground roads.

The writer does not profess to have exhausted the subject, but he hopes by thus drawing attention to it that he will be the means of increasing amongst miners a knowledge of it.

There are one or two other points in the subject which he would like to have gone into, but circumstances do not permit him to go further into the matter at present.

His desire in compiling these articles has been to make them of utility to practical men, and he will be glad to know if he has in any degree succeeded in his object.

THE VENTILATION OF COAL MINES.

1. Motion in air is caused by pressure or difference of pressure—pressure is obtained by difference in density—and the movement is in the direction from the heavier to the lighter air. Pressure, or difference of pressure, as regards air circulating in mines, may be obtained either by the application of heat as by a furnace, or by exhausting the air mechanically from the workings by a fan; it is no matter which of these means is applied to procure difference of pressure, the result will be the same with the same difference of pressure however obtained.

2. If there are two shafts of equal depth, having a passage at the bottom connecting them, and the temperature and density of the air are the same in each shaft, then, as there is nothing to

destroy the equilibrium of pressure, the air will remain stagnant.

3. If by some artificial means, as by a furnace, the temperature of one of the shafts is raised above that of the other, or there is an exudation of the lighter gases, then the air in that shaft will be less dense, and the air will move in that direction from the colder shaft—the heavier column descending and forcing up the lighter one with a velocity proportionate to the pressure caused by the difference of density.

4. If the tops of the two shafts were not on the same level, the atmospheric pressure would be the same at the same level above the surface, and the extra head of air above the shorter shaft, forming part of the outward atmosphere, would have the same effect as if it were contained in a shaft which rose to the same height. In this case, if the external temperature were lower than the temperature of the strata in which the shafts and the passage were made, the circulation of the air would be down the shorter shaft and up the longer

one. On the other hand, if the exterior temperature be higher than that of the shafts and strata, the shorter shaft will be the upcast.

5. The *motive column* is a head of air of such a height that it will equal the difference of the weight between the air in the downcast and upcast shafts; and it is found by calculation from this rule:

$$M = D \times \frac{t_2 - t_1}{459 + t_2}$$

M = motive column D = depth of upcast in feet, t_1 and t_2 represent the temperatures of the downcast and upcast shafts respectively.

6. The motive column is really a measure of the pressure in force producing the ventilation, and if it is required to express it in pounds per square foot it may be calculated by multiplying the depth of the shaft in feet by the weight of one foot of air at the average temperature of the air in the shaft. Do this for each shaft and deduct the one from the other, the difference will be the pressure producing the ventilation. The follow-

ing table gives the weight of a foot of air at various temperatures, and may be found useful to the student for this and other purposes.

TABLE showing the weight of a cubic foot of air in decimals of a pound avoirdupois, at different temperatures, calculated from the formula

$$W = \frac{1.32529 \times 30}{459 + t} = \frac{39.7587}{459 + t}$$

Temperature t.	Weight in decimals of a lb.	Temperature t.	Weight in decimals of a lb.
32	.0809749	120	.0686678
35	.0804831	125	.0680799
40	.0796767	130	.0675020
45	.0788863	135	.0669338
50	.0781113	140	.0663751
55	.0773515	145	.0658256
60	.0766063	150	.0652852
62	.0763122	155	.0647535
65	.0758753	160	.0642305
70	.0751582	165	.0637158
75	.0744544	170	.0632093
80	.0737638	175	.0627108
85	.0730858	180	.0622201
90	.0724202	185	.0617371
95	.0717666	190	.0612614
100	.0711246	195	.0607931
105	.0704941	200	.0603318
110	.0698746	205	.0598775
115	.0692660	212	.0592529

7. The force which operates in putting air in motion may likewise be expressed by saying it is equal to so much water-gauge, generally expressed in inches and decimals. With air and water at a temperature of 62°, the following rules will apply for converting the pressure into different terms:

Water gauge in inches $\times$ 5.196 = pounds per square foot.

Pounds per square foot divided by .0763122 = length of motive column in feet.

8. The velocity of air without resistance is the same that a body would attain in falling the height of the motive column, so that if there is a difference of pressure equal to 34 ft. of air column, the theoretical velocity of the air would be about 47 ft. per second, because a falling body under the force of gravity, would attain a velocity of 8.025 times the square root of 34, or 47 nearly. It will thus be seen that were it not for the resistances encountered by air in passing along underground roads, a very small pressure

would suffice to produce a great velocity. To show the theoretical velocity due to various pressures or motive columns, the table following has been constructed; from this we see that with 2 in. of water gauge, a very common pressure in colliery ventilation, a velocity of 93 ft. per second would be attained, but as air is retarded in its movement by rubbing against the sides of the channels, nothing like the theoretical velocity is reached in practice. The table shows likewise the pressure variously in pounds per square foot, inches of water gauge and feet of air column.

9. In practice from ten to twenty times as much pressure is required to give that momentum to the air which would suffice for the final velocity, on account of the friction air meets with in rubbing against the sides of the airways in passing round the underground workings.

10. If the whole friction of a mine be measured by 2.18 in. of water gauge, and the final velocity of the air in the upcast is 30 ft. per second—a common enough

TABLE SHOWING THE AMOUNT OF MOTIVE COLUMN OF AIR AND INCHES OF WATER GAUGE NECESSARY TO PRODUCE THE THEORETICAL FINAL VELOCITY IN UP-CAST SHAFTS, WITH AIR AT DIFFERENT TEMPERATURES

Velocity in feet per second.	Motive column of air.	Water gauge in decimals of an inch at the following temperatures.								
$A=8.025\sqrt{B}$	$B=\frac{A^2}{64.4}$	$C=\frac{\frac{1.32529 \times 30}{459+t}}{5.196} \times B.$								
		Degs. 90	Degs. 105	Degs. 120	Degs. 135	Degs. 150	Degs. 165	Degs. 180	Degs. 195	Degs. 210
5	.39	.005	.005	.005	.005	.005	.005	.005	.005	.004
10	1.55	.022	.021	.020	.020	.019	.019	.019	.018	.018
15	3.49	.049	.047	.046	.045	.044	.043	.042	.041	.040
20	6.21	.087	.084	.082	.080	.078	.076	.074	.073	.071
25	9.70	.135	.132	.128	.125	.122	.119	.116	.113	.111
30	13.98	.195	.190	.185	.180	.176	.171	.167	.164	.160
35	19.02	.265	.258	.251	.245	.239	.233	.228	.223	.218
40	24.84	.346	.337	.328	.320	.312	.305	.297	.291	.284

TABLE showing the comparative height of water gauge and air column at a temperature of 62 degs. Fahr., with pressure in pounds per square foot and theoretical velocity of air due to this pressure.

NOTE.—Weight of cubic foot of air at 62 degs. =.0763122 lb., and of water =62.355 lb.

Water-gauge in inches.	Pressure in pounds per square foot.	Motive column of air in feet.	Velocity of air in feet per second due to motive column.
$A = \frac{B}{5.196}$	$B = \frac{A \times 62.355}{12}$	$C = \frac{B}{.0763122}$	$D = 8.025 \sqrt{C}$
.1	.5196	6.81	21
.2	1.0392	13.62	30
.3	1.5588	20.43	36
.4	2.0784	27.24	42
.5	2.598	34.04	47
.6	3.1176	40.85	51
.7	3.6372	47.66	55
.8	4.1568	54.47	59
.9	4.6764	61.28	63
1.0	5.196	68.09	66
2.0	10.392	136.18	94
3.0	15.588	204.27	115
4.0	20.784	272.36	132
5.0	25.980	340.45	148
6.0	31.176	408.55	162

velocity in furnace shafts—the temperature of which is, say 135°, it will be found by calculation that 2 in. of this pressure is due to friction, the decimal portion only being required to próduce the velocity, the water gauge due to final velocity being found thus:

$$\frac{\frac{30^2}{64.4} \times \frac{1.32529 \times 30}{459 + t}}{5.196}$$

The table given on page 18 has been prepared to show the height of water gauge required to generate the theoretical final velocities at various temperatures; this deducted from the total height of water gauge gives that which is to be referred to friction.

Example:—The quantity of air passing in an upcast having an area of 140 ft., is 210,000 cubic ft. per minute; the velocity is therefore 25 ft. per second, the temperature is 210°, then the water gauge due to velocity is by the table equal to .111 inch.

THE RESISTANCE OF AIR IN MOVING ALONG UNDERGROUND PASSAGES.

11. All experiments hitherto made with respect to the movement of fluids of every kind in pipes, passages or channels tend to prove that the resistance to the motion of the fluids is in proportion to the length of the passages traversed, to the perimeter of the section of the passages, to the square of the mean velocity of the fluids, and in inverse ratio to the section, or nearly so.

12. The following rules apply to the friction of air in moving along level passages of uniform size:—Let a = area of airways in square feet; h = horse power of ventilation; k = co-efficient of friction; l = length of air channel; o = perimeter of air channel; p = pressure in pounds per square foot; q = quantity of air circulating in cubic feet per minute; s = area in square feet of rubbing surface

exposed to the air; u = units of work, foot pounds or power applied to circulate the air; v=velocity of the air in feet per minute; w=water gauge in inches; then

1.—$a=\frac{ksv^2}{p}=\frac{pa}{p}=\frac{ksv^2q}{u}=\frac{ksv^2}{pv}=$

$$\frac{u}{pv}=\frac{q}{v}=\sqrt[3]{\frac{u}{ks}}$$

2.—$h=\frac{u}{33000}=\frac{qp}{33000}$ &c.

3.—$k=\frac{pa}{sv^2}=\frac{u}{sv^3}=\frac{p}{\frac{sv^2}{a}}=\frac{w5\frac{1}{5}}{\frac{sv^2}{a}}$.

4.—$l=\frac{s}{o}$.

5.—$o=\frac{s}{l}$.

6.—$p=\frac{ksv^2}{a}=\frac{u}{q}=5\frac{1}{5}w=\left(\sqrt[3]{\frac{u}{ks}}\right)^2\frac{ks}{a}=$

$$\frac{pa}{a}=\frac{ksv^2}{q}=\frac{u}{av}.$$

7.—$pa=ksv^2=\left(\sqrt[3]{\frac{u}{ks}}\right)^2ks=\frac{u}{v}$.

8.—$q = va = \frac{u}{p} = \frac{ksv^3}{p} =$

$$\sqrt{\frac{pa}{ks}}\,a = \sqrt[3]{\frac{u}{ks}}\,a.$$

9.—$s = \frac{pa}{kv^2} = \frac{u}{kv^3} = \frac{qp}{kv^3} = \frac{vpa}{kv^3} = lo.$

10.—$u = qp = vpa = \frac{ksv^3q}{a} = ksv^3 =$

$$q\,5\tfrac{1}{5}\,w = h\ 33{,}000.$$

11.—$v = \frac{u}{pa} = \frac{q}{a} = \sqrt[3]{\frac{u}{ks}} = \sqrt[3]{\frac{qp}{ks}} = \sqrt[2]{\frac{pa}{ks}}.$

12.—$v^2 = \frac{pa}{ks} = \left(\sqrt[3]{\frac{u}{ks}}\right)^2.$

13.—$v^3 = \frac{u}{ks} = \frac{qp}{ks} = \frac{vpa}{ks}.$

14.—$w = \frac{\frac{ksv^2}{a}}{5\frac{1}{5}} = \frac{p}{5\frac{1}{5}}.$

13. These formulæ comprise the pressure referable to resistance, but not that necessary for producing velocity; so that they may be looked upon as more correct for long passages than short ones; that is to say, the pressure required for the final velocity becomes a

smaller fractional part of the whole drag as the pit workings extend. In a general way, for the sake of simplicity, the student need not take into account the pressure necessary for velocity; but if he desires to do so, instead of using p let him use $p-p_v$; p_v being the pressure required to generate the final velocity. In this case,

Instead of using $a=\frac{ksv^2}{p}$ substitute $\frac{ksv^2}{p-p_v}$.

Instead of $pa=ksv^2$, use $a(p-p_v)=ksv^2$.

Instead of $p=\frac{ksv^2}{a}$, use $p-p_v=\frac{ksv^2}{a}$, or

$$p=\frac{ksv^2}{a}+p_v.$$

Instead of $s=\frac{pa}{kv^2}$, use $\frac{(p-p_v)a}{kv^2}$.

Instead of $v=\sqrt{\frac{pa}{ks}}$ use $\sqrt[2]{\frac{(p-p_v)a}{ks}}$.

14. The co-efficient that will be used in working out the examples given in the following paragraphs will be that adopted by Mr. Atkinson, viz., .0217 lb. per square foot of area of section for every foot of

rubbing surface and for a velocity in the air of 1,000 ft. per minute; or .0000000217 lb. for a velocity of one foot per minute, or $\frac{1}{46082950}$.

15. The area of a road, if square or rectangular, is found by multiplying the two sides together; thus a road 6 ft. high and 5 ft. wide = 30 ft. area. The perimeter of the same road would be $2 \times 6 + 2 \times 5 = 22$.

The rubbing surface is found by multiplying the perimeter by the length; thus a road to continue for 1,000 yards in length, and measuring 6 ft. × 5 ft., would have a rubbing surface (s) of $(1{,}000 \times 3 \times 22) = 66{,}000$ square feet.

17. The quantity of air in cubic feet per minute is obtained by multiplying the velocity in feet per minute by the area; the horse power is obtained by multiplying the quantity by the pressure and dividing by 33,000.

18. The student must take care to clearly understand the difference between pressure (p) and power (u). Pressure is

the force per square foot producing the ventilation, and power is the quantity passing multiplied by the pressure.

19. The co-efficient is found by dividing the pressure by the rubbing surface, multiplied by the velocity squared, divided by the area, or the value of $\frac{sv^2}{a}$ divided in the pressure (p).

20. The resistance is according to the length of the air channel for the same quantity of air, thus, if a mine were extended from 1,000 to 2,000 yards, the resistance would be doubled.

21. The resistance is according to the square of the velocity, and aircourses having the same pressure, area and perimeter, but different lengths, will pass quantities in accordance with the reciprocal of the square root of the length, or the square foot of the length divided into one. Suppose an aircourse 200 yards long pass 7,071 cubic feet, the quantities that will pass in aircourses of 400 and 600 yards long, with the same pressure, area, and perimeter, will be

5,000, and 4,082 respectively, because $\sqrt{\frac{1}{200}}=.07071$; $\sqrt{\frac{1}{400}}=.05$; $\sqrt{\frac{1}{600}}=$ .04082 and the fact that lq^2 for each airway gives the same result proves the question.

22. The quantity of air circulating in a mine is according to the square root of the pressure; in furnace ventilation the pressure increases with the depth (provided the difference of temperature between the two shafts be maintained) and the ventilation with the square root of the depth of the upcast, so that by adding a stack of 30 ft. at the top of an upcast 150 fathoms deep the ventilation capabilities would be increased about $\frac{1}{60}$th.

23. If we obtain a certain quantity by a furnace and another by steam jet or other means, the combined effect will be according to the square root of the square of the one added to the square of the other; for example, if a mine circulates 25,000 cubic feet of air per minute by furnace alone, and 22,000 by steam

jets alone, the quantity of air that will pass with the two acting together will be be $\sqrt{25000^2+22000^2}=33{,}301$.

24. The quantity of air passing is according to the cube root of the power applied, and *vice versa*, the power necessary is according to the cube of the quantity; thus to treble the quantity of air in a mine the power necessary would be twenty-seven times as much, and if by an expenditure of 70,087 units of work 16,848 cubic feet be obtained, the quantity that would be got by employing 277,045 units would be 26,639, because:

$$\frac{16848\times\sqrt[3]{277045}}{\sqrt[3]{70087}}=26639$$

25. The quantity of air passing in airways of different areas, other things being equal is according to the square root of the area multiplied by the area. Thus, the pressure and rubbing surface being the same in each case, the quantity passing in an airway of 30 ft. area, when 20,000 ft. pass in one of 60 ft. area, will be 7,071, because

$$\frac{\sqrt{30}\times 20000}{\sqrt{60}}\times\frac{30}{60}=7{,}071.$$

26. To make airways of different lengths of such area as to pass an equal quantity with the same pressure, apportion them according to the formula

$$a=\frac{q}{\sqrt[3]{\frac{u}{ks}}}$$

Thus, in a coal mine ventilated by five different splits or air currents:

The first	200	yards long	and	9	ft.	area,
" second	400	"	"	?	"	
" third	600	"	"	?	"	
" fourth	800	"	"	?	"	
" fifth	1,000	"	"	?	"	

The areas of each of these, to pass the same quantities with the same pressure, will be found thus: reckoning the perimeter to be the same in each case, and taking the length in feet as the rubbing surface, and 10,000 cubic feet as the quantity passing in each road, then u

will be found for the first airway by $\left(\frac{ksv^2}{a}\right)\times q = 17{,}860$, and the value of $\sqrt[3]{\frac{u}{ks}}$ in each of the other roads is:

2nd, 881.883,
3rd, 770.400,
4th, 699.955,
5th, 649.780, then:

$$2.—\frac{10000}{881.883}=11.339 \text{ area.}$$

$$3.—\frac{10000}{770.400}=12.980 \quad \text{“}$$

$$4.—\frac{10000}{699.955}=14.286 \quad \text{“}$$

$$5.—\frac{10000}{649.780}=15.389 \quad \text{“}$$

and the correctness of these areas is proved by finding the amount of pressure, p, for the assumed quantity, which ought to be the same in each case as below:

$$\left(p=\frac{ksv^2}{a}\right)$$

$$1.—\frac{.0000000217 \times 600 \times \left(\frac{10000}{9}\right)^2}{9} = 1.786 \text{ lb.}$$

$$2.—\frac{.0000000217 \times 1200 \times \left(\frac{10000}{11.339}\right)^2}{11.339} = 1.786 \text{ lb.}$$

$$3.—\frac{.0000000217 \times 1800 \times \left(\frac{10000}{12.98}\right)^2}{12.98} = 1.785 \text{ lb.}$$

$$4.—\frac{.0000000217 \times 3000 \times \left(\frac{10000}{15.389}\right)^2}{15.389} = 1.785 \text{ lb.}$$

which is sufficiently near. Or, as in this question the quantity (q), the power (u), k and q are all the same, we may cancel these factors in the equation $a = \frac{q}{\sqrt[3]{\frac{u}{ks}}}$ which will then be reduced to $\sqrt[3]{s}$, then the areas will be simply according to the cube root of the rubbing surface (s); and, as in this we consider the length as the rubbing surface, because the peri-

meters are all taken as equal, the result will be according to the cube root of the length, thus:

1. $\sqrt[3]{600} = 8.4343.$
2. $\sqrt[3]{1200} = 10.6269.$
3. $\sqrt[3]{1800} = 12.1644$
4. $\sqrt[3]{2400} = 13.3884.$
5. $\sqrt[3]{3000} = 14.4222.$

We now say:

		area.	
If 8.4343 : 9 : :	10.6269 =	11.339	of 2nd airway.
" 8.4343 : 9 : :	12.1644 =	12.980	of 3rd "
" 8.4343 : 9 : :	13.3884 =	14.286	of 4th "
" 8.4343 : 9 : :	14.4222 =	15.389	of 5th "

which areas are precisely the same as those obtained above.

27. If a continuous undivided road passing one current of air be of various dimensions, for the purposes of calculation it may be reduced to one typical road of uniform size throughout, the length (l') of which may be found by this rule:

$$l' = \frac{a'^3}{o'} \times \frac{s}{a^3}.$$

a'=area of typical road; o' perimeter of same, s and a = rubbing surface and area respectively of the original uneven road at each series of dimensions.

EXAMPLE: The following are the measurements of an airway, and it is desired to calculate the length of a typical road which will measure 6 ft. square uniformly throughout, and that will offer equal resistance to it.

With a road 6 ft. square, $\frac{a'^3}{o'}$ will equal 1,944.

Length l. Feet.	Size.	Area. a Feet.	Perimeter. o. Feet.	Rubbing surface. $s=lo$. Feet.	Length of typical road $=l'=1944\times\frac{s}{a^2}$.
700	7×5	35	24	16,800	761.7
300	4×5	20	18	5,400	1312.2
400	8×3	24	22	8,800	1237.5
500	6×5	30	22	11,000	792.
200	4×4	16	16	3,200	1518.6
2,100		Length of Original road.	Length of Typical road.		5622.

Thus we see that the length of the new

road would be 5,622, the old one being 2,100 ft.; and this may be proved in the following manner:—Put the quantity of air passing at 10,500 cubic feet per minute, then the pressure (p) for each part of the original road will be found by $\frac{ksv^2}{a} =$ lbs.

Each part of the original road.

1.— $\frac{.0000000217 \times 16800 \times 300^2}{35} = .9374$

2.— $\frac{.0000000217 \times 5400 \times 525^2}{20} = 1.6148$

3.— $\frac{.0000000217 \times 8800 \times 437.5^2}{24} = 1.5229$

4.— $\frac{.0000000217 \times 11000 \times 350^2}{30} = .9747$

5.— $\frac{.0000000217 \times 3200 \times 656.25^2}{16} = 1.8690$

Typical road:

$$\frac{.0000000217 \times 134928 \times 291.6666^2}{36} = 6.9188$$

The correctness of the result is shown by the pressure, p, required to pass the same quantity (which is taken at 10,500)

through the typical road, being the same as is required in all the different parts of the original road put together, viz., 6.9188 lbs.

There are one or two useful practical lessons to be learnt from this illustration. In the first place it will be seen that the typical road of 6 ft. square and 5,622 ft. long will offer exactly the same amount of resistance—with the same quantity of air in motion—that is offered by the irregular road, the dimensions of which are expressed in the five series of figures. It is noteworthy that that part of the uneven road measuring 700 ft. long, and 7 ft. by 5 ft., only requires about half the pressure which is necessary to keep in circulation the same amount of air in that portion of the road measuring 200 ft. long, and 4 ft. by 4 ft.; this is of great importance practically and shows how the ventilating power of mines may be used up and wasted, as indeed, it too often is, by contracted airways.

28. The power required to circulate 10,500 ft. of air through an airway 1,000

yards long and 7 ft. by 5 ft., amounts to 42,182 units per minute, whereas the power required to circulate the same quantity through a road the same length, but only 4 ft. square, would amount to 294,368 units per minute. In other words, it would require an engine nearly seven times the power to pass the same quantity through the smaller airway as through the larger one.

29. The relative powers required to pass equal quantities of air through air-courses of the same length, but different areas and perimeters (o) will be found by this rule—$o\left(\frac{1}{a}\right)^3$,—and the table below shows the result of this worked out for five different sized airways:

Size of airways.	o.	a.	$o\left(\frac{1}{a}\right)^3 =$	Relative powers making the road. $6 \times 6 = 1$.
6 × 6	24	36	.0005144	1.
5 × 5	20	25	.0012800	2.29
4 × 4	16	16	.0039062	7.59
3 × 3	12	9	.0164608	32.
2 × 2	8	4	.1250000	243.

Thus it will be seen that to pass the same quantity of air through a road 3 ft. square as through one 6 ft. square of the same length will require thirty-two times the power, &c.

30. In a channel or aircourse of uneven area and perimeter along which the air travels in one current, and which in calculation must be taken in a series of lengths of uniform size, the proportion of pressure or power that is taken up by each part of the road will be found by this rule $s\frac{\left(\frac{1}{a}\right)^2}{a}$, or $s\left(\frac{1}{a}\right)^3$

31. The pressure or power required to overcome the friction in passing equal quantities of air through circular airways or shafts is in inverse proportion to the fifth power of their diameters, or directly in proportion to $o\left(\frac{1}{a}\right)^3$.

The table on next page shows the relative pressure and powers required to overcome the friction in passing the same

quantities of air through airways or shafts of the given diameters.

By the table it will be seen that 243 times the power will be required to pass the same quantity of air through a shaft

Diameter of shaft or airway.	Rule.	Relative powers for the same quantity.
18	—	1.
16	$\frac{18^5}{16^5}=$	1.80
14	$\frac{18^5}{14^5}=$	3.51
12	$\frac{18^5}{12^5}=$	7.59
10	$\frac{18^5}{10^5}=$	18.89
8	$\frac{18^5}{8^5}=$	57.66
6	$\frac{18^5}{6^5}=$	243.

6 ft. diameter that is required to pass it through an 18 ft. pit, or through airways of these dimensions. The reader will do well to prove this, and he may do so by taking the usual co-efficient, and ascer-

taining the powers necessary for passing, say, 30,000 ft. of air through two airways, say, of 6 ft. and 18 ft. diameter respectively, and each, say, 500 yards long. This will be found by the rule $u = \frac{ksv^2q}{a}$, which for the 6 ft. diameter channel will be:

$$\frac{.0000000217 \times 28274.4 \times 1061.04^2 \times 30000}{28.274} =$$

732,839 units, and for the channel 18 ft. diameter:

$$\frac{.0000000217 \times 84823.2 \times 117.89^2 \times 30000}{254.469} =$$

30,169 units, and $\frac{732839}{3016} = 243$ nearly, which proves the question.

And the quantity of air that will pass in such airways with the same power is in inverse proportion to the cube root of the relative powers; or with the same pressure in inverse proportion to the square root of the relative powers.

THE EFFECT OF SPLITTING THE AIR.

32. In this place it seems desirable to explain what is meant by "splitting the air." Originally it was the usual custom to circulate the air through a mine in one undivided current, down one shaft, around the workings, and up the other shaft, and this plan is still in use in some simple cases. When this one current is divided in the mine into two or more currents, which unite again at or before reaching the upcast, it is said to be split. Splits may be of equal or unequal length and area. The expression "two equal splits" means that the original one current is divided into two currents, each of half the length, but both with the same area as the original one. It must be noted that the phrase "equal splits" is more a mathematical than a practical one, for it may be safely said that to split a current into two, three, or

more equal dimensions is never done practically; it can, however, in some cases be done nearly. After this explanation it will be understood that theoretical splitting will always show a somewhat better result than practical splitting, because, owing to the varied circumstances of the mine, the air cannot always be exactly equally divided, and in practice, as a rule, the aggregate length of the various splits will be somewhat longer than the original one current; or the splitting will take place too far in-bye, or reunite again too far away from the bottom of the upcast. No one understood this better than the late Mr. Atkinson; hence he says:—"Every principal split of air should commence as near as possible to the bottom of the downcast shaft, and should have a distinct airway to return in."

In the calculations which will be brought forward in this chapter with reference to splitting, it will be on the assumption that the splits take place at the bottom of the downcast, and re-unite

at the bottom of the upcast—in fact that the splits are equal. Unequal splitting will be taken into consideration in the next section.

Suppose the original aircourse of the mine to measure 40 ft. area (a), and 120,000 rubbing surface (s); by splitting into two equal currents we should get two airways each 40 ft. area (a) and 60,000 rubbing surface; by splitting into three currents we should have three airways, each 40 ft. area and 40,000 rubbing surface; the area, after splitting, being two or three times that of the original airway, according to the number of splits, but the total rubbing surface remaining the same throughout.

It is necessary here to explain further that when this original one current is divided into two equal splits, they may be considered as one current with double the area, but with the same rubbing surface. When divided into three equal splits, these three divisions may be considered as one airway of treble the orig-

inal area, but with the same rubbing surface, in fact, as tabulated below:

		a.	*s.*
Original current.....		40	120,000
Two equal splits.....	1...	40	60,000
	1...	40	60,000
Equal one current.....		80	120,000
Three equal splits.....	1...	40	40,000
	1...	40	40,000
	1...	40	40,000
Equal one current.....		120	120,000

This will be proved arithmetically further on.

33. The benefit derived from splitting depends very much upon the relative rubbing surfaces and the areas of the shafts, as compared with those of the mine, and unless the friction due to the shafts be taken into account when the effect of splitting is calculated, the result will be fallacious.

Were it not for the resistance of the shafts, which, of course, varies with the

quantity of air passing, the result of splitting would be more easily calculated.

34. It may perhaps be better, for the sake of the student, that we should in the first place consider the effect of splitting without taking into account the shaft resistances, so that he may acquaint himself gradually with the process of calculation, and eventually see the difference of the two results.

35. The following example is given for calculation: the quantity of air passing round a mine in one current before splitting is 10,000 cubic feet per minute; the area of the aircourse is 20 ft., and the rubbing surface is 24,000, what quantity will circulate when the current is split into 2, 3, 4, 5, 6, and 10 equal divisions, the pressure remaining the same?

In the first place the pressure (p) for the one current may be found by the rule $\frac{ksv^2}{a}$, this will be 6.51 lbs. The effect of splitting into 2, 3, &c., divisions, as has been

explained in paragraph 31, is to double, treble, &c., the area, without altering the rubbing surface, and as the quantity is obtained by the rule $\sqrt{\frac{pa}{ks}} \times a$, we use this to find the quantities with the various splits in operation; but as p, k, and s are the same in all these instances, the formula will be reduced to this simple rule $\sqrt{a} \times a$, and the relative quantities will be according to the square root of the area multiplied by the area, as tabulated below:

No. of splits.	s.	a.	$q = \sqrt{\frac{pa}{ks}} \times a$.	$p = \frac{ksv^2}{a}$
1	24,000	20	10,000	6.51
2	24,000	40	28,284	6.51
3	24,000	60	61,961	6.51
4	24,000	80	80,000	6.51
5	24,000	100	111,803	6.51
6	24,000	120	146,969	6.51
10	24,000	200	316,228	6.51

or the question may be worked out without reference to the actual dimensions of the areas and rubbing surfaces in each

case, further than considering the areas to vary as 1, 2, 3, 4, &c. Then the quantities that will pass will be most simply found thus:—If $\sqrt{1}\times 1 : 10{,}000 :: \sqrt{2}\times 2 : = 28{,}284$, the quantity with two splits, and if $\sqrt{1}\times 1 : 10{,}000 :: {}^{2}\sqrt{10}\times 10 : = 316{,}228$, the quantity with ten splits as above.

An example similar to this is given further on, showing what the result will be after taking into account the shaft resistances.

36. If the power is to remain the same, instead of the pressure, and the original aircourse passing 10,000 cubic feet per minute, the quantity that will pass in each case of 2, 3, 4, 5, 6, and 10 equal splits will be simply in direct proportion to the area:—1, 10,000; 2, 20,000; 3, 30,000; 4, 40,000; 5, 50,000; 6, 60,000; 10, 100,000. The rule to find the quantity when the power (u) is given being ${}^{3}\sqrt{\frac{u}{ks}}\times a$, but k, s and u being the same in the case of all the splits, these may be canceled, and the quantities will be di-

rectly according to the area as stated above.

37. There is a great difference between splitting the air and adding an additional aircourse of the same length and area as the original one; thus, in dividing one current into two equal splits, we get an increase from 10,000 to 20,000 with the same power, but by adding an additional aircourse the increase will only be from 10,000 to 15,874; this may be worked out as follows:

Take a to equal 36 and s to equal 18,000, then the power is found by the formula $\frac{ksv^3q}{a}=8371.4$ foot pounds $= u$. With the additional aircourse "a" and "s" will be doubled, and as the velocity is got by $\sqrt[3]{\frac{u}{ks}}$, we use these figures $\sqrt[3]{\frac{8371.4}{.0000000217\times36000}}\times72$, to get the quantity which is equal to 15,874 cubic feet per minute, or the quantity is according to the reciprocal of the cube root of the rubbing surface multiplied by the

area; as both s and a are in the proportion of one to two we say,

If $\sqrt[3]{\frac{1}{1}} \times 1 : 10{,}000 :: \sqrt[3]{\frac{1}{2}} \times 2 : = 15{,}874$,

the same as above.

38. So far, we have not taken into account the shaft resistances, but in the next example we will do so.

If there are 10,000 cubic feet of air passing through a mine in one current, the resistances of the shafts at that time being equal to the resistance of the mine, what extra quantity of air will pass through the mine by adding an additional aircourse, same length and area as the original one, the power remaining the same?

In order to make the resistance of the shafts and mine equal, take the area and rubbing surface of each the same. With the addition of another aircourse, both the area and rubbing surfaces in the mine are doubled. Proceeding in this way, the results have been obtained as follows:

Divisions of air.		q.	a.	s.	p.	u.
1	Shafts..	10,000	36	18,000	.83714	8371.4
	Mine...	10,000	36	18,000	.83714	8371.4
	Total...			36,000		16742 8
2	Shafts..	11,694	36	18,000	1.1455	13394.3
	Mine...	11,694	72	36,000	.28662	3348.5
	Total...					16742.8

Having taken the area of the shaft and mine at 36, and rubbing surface of each at 18,000 with one current, we find that the power required to pass 10,000 ft. through the mine and shafts amounts to 16742.8 foot pounds (u). The value of p is obtained by

$$\frac{\left(\frac{q}{a}\right)^2 \times s \times k,}{a} \text{ and of } u \text{ by } q\,p.$$

Now, in order to apportion the power that will be used up by the shaft and mine after making the additional air-course, we put the two aircourses of the mine into one, the dimensions of which will be 72 a and 36,000 s; and use the

formula given in paragraph 30, viz., $\left(\frac{1}{a}\right)^3$. By this we find 13394.3 units are required to pass the same quantity of 11,694 cubic feet per minute through the shafts that 3348.5 units will pass through the mine. Or, the power used in the shafts will be found thus:

$$\frac{16742.8 \times 18000 \times \left(\frac{1}{36}\right)^3}{18000 \times \left(\frac{1}{36}\right)^3 + 36000 \times \left(\frac{1}{72}\right)^3} = 13394.3$$

that of the mine thus:

$$\frac{16742.8 \times 36000 \times \left(\frac{1}{72}\right)^3}{18000 \times \left(\frac{1}{36}\right)^3 + 36000 \left(\frac{1}{72}\right)^3} = 3348.5$$

Total..... 16742.8

39. If the resistances of the shafts are half those of the mine when there are five equal splits, and there are 10,000 ft. of air passing in one current before being split at all, the quantities that will pass through the mine with 2, 3, 4, 5, 6, and 10 equal splits are stated in the table on pages 50 and 51, the same ventilating pressure being in operation.

Division of the current.		Relatively.		
		s.	a.	$p = \frac{s\left(\frac{1}{a}\right)^2}{a}$
		1.	2.	3.
1	Shafts.....	1	10	.001
	Mine.....	2	2	.25
				.251
2	Shafts.....	1	10	.001
	Mine.....	2	4	.03125
				.03225
3	Shafts.....	1	10	.001
	Mine.....	2	6	.009259
				.010259
4	Shafts.....	1	10	.001
	Mine.....	2	8	.00390625
				.00490625
5	Shafts.....	1	10	.001
	Mine.....	2	10	.002
				.003
6	Shafts.....	1	10	.001
	Mine.....	2	12	.0011574
				.0021574
10	Shafts.....	1	10	.001
	Mine.....	2	20	.00025
				.00125

Actual.			
s.	a.	p.	$q = \sqrt[2]{\frac{pa}{ks}} \times a$
4.	5.	6.	7.
12,000	100	.02604	10,000
24,000	20	6.51	10,000
		6.53604	
12,000	100	.20267	27,898
24,000	40	6.33337	27,898
		6.53604	
12,000	100	.63710	49,463
24,000	60	5.89894	49,463
		6.53604	
12,000	100	1.33219	71,526
24,000	80	5.20385	71,526
		6.53604	
12,000	100	2.17868	91,469
24,000	100	4.35736	91,469
		6.53604	
12,000	100	3.02969	107,863
24,000	120	3.50645	107,863
		6.53604	
12,000	100	5.22883	141,704
24,000	200	1.30721	141,704
		6.53604	

In this table it is shown that, with six equal splits and area taken at 120, and rubbing surface 24,000 the pressure required to pass 107,863 ft. through the mine is 3.50645. Here we have taken the six equal splits as one current, and to show that this one current would be equal to the six splits taken collectively we give the following figures:

	s.	*a.*	*p.*	*q.*
6 equal splits =	4000	20	3.50645	$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$
	4000	20		$17977\frac{1}{6}$

All the splits are reckoned to be divided at the bottom of the downcast, and to re-unite at the bottom of the upcast. They are therefore all to be considered as subject to one common pressure; taking this for each at 3.50645, and using the formula $\sqrt[2]{\frac{pa}{ks}} \times a$, we shall find that each separate split will pass $17977\frac{1}{6}$ ft.,

and the total quantity in the six splits will be 107,863 ft., and therefore one current having $s = 24{,}000$ and $a = 120$ is equal to six divisions taken together, each of them having $s = 4000$ and $a = 20$.

Here a of shafts has been made to equal 100 and $s = 12{,}000$, and of mine when there are five splits $a = 100$, $s = 24{,}000$, for by these conditions we shall have the resistances of the shafts half those of the mine when there are five equal splits, as desired in the question. In explanation of the figures given under columns s, a, and p "relatively," it may be said that the rubbing surfaces of the shafts and mine are in the proportion of 1 and 2, both in the case of the one current, and all the splits and the areas are in the proportions given in the second column; the third column shows the relative pressure required to pass equal quantities through airways having the conditions given in columns 1 and 2. With reference to the figures in column 6, they are obtained by apportioning them according to their relative press-

ures in the third column; thus, the pressure per foot at work in producing the ventilation is 6.53604 lbs., when 10,000 ft. pass in the one current, the result being got at by working out both for the shafts and mine the rule $\frac{\left(\frac{q}{a}\right)^2 \times s \times k}{a}$; and we say, for example, in the case of two splits, if .03225 give 6.53604, what will .001 give? and, if .03225 give 6.53604, what will .03125 give? by which we obtain .20267, the pressure required in the shafts, and 6.33337, the pressure required for an equal quantity of air in the mine; and so for the other splits. The quantity in the seventh column is obtained by $\sqrt[2]{\frac{pa}{ks}} \times a$; or the result may be determined more directly by using the relative pressures obtained in column 3; the quantities will be according to the square root of these, thus:

$$\text{With 2 splits} = \frac{\sqrt{\frac{.001}{.03225}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 27898.$$

$$\text{With 3 splits} = \frac{\sqrt{\frac{.001}{.010259}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 49463.$$

$$\text{With 4 splits} = \frac{\sqrt{\frac{.001}{.00490625}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 71526.$$

$$\text{With 5 splits} = \frac{\sqrt{\frac{.001}{.003}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 91469.$$

$$\text{With 6 splits} = \frac{\sqrt{\frac{.001}{.0021574}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 107863.$$

$$\text{With 10 splits} = \frac{\sqrt{\frac{.001}{.00125}} \times 10000}{\sqrt{\frac{.001}{.251}}} = 141704.$$

40. Considering the resistances of the shaft and mine in the same proportion as in the previous example, but reckoning the power to remain the same throughout, the accompanying table (see pages 58 and 59) shows the quantity that will pass with the various splits.

Having explained in the remarks on the previous table how the quantities have been found, it seems unnecessary to do so in this case; indeed, the tables are so constructed as to obviate as much as possible the necessity of explanation. The results given in this table may be found more directly by using the relative powers in the third column of the table; the quantities will be according to the cube root of these:

$$\text{With 2 splits} = \frac{\sqrt[3]{\frac{.001}{.03225}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 19817.$$

$$\text{With 3 splits} = \frac{\sqrt[3]{\frac{.001}{.010259}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 29030.$$

$$\text{With 4 splits} = \frac{\sqrt[3]{\frac{.001}{.00490625}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 37123.$$

$$\text{With 5 splits} = \frac{\sqrt[3]{\frac{.001}{.003}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 43737.$$

$$\text{With 6 splits} = \frac{\sqrt[3]{\frac{.001}{.0021574}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 48818.$$

$$\text{With 10 splits} = \frac{\sqrt[3]{\frac{.001}{.00125}} \times 10000}{\sqrt[3]{\frac{.001}{.251}}} = 58558.$$

41. Mr. Atkinson, in his *Treatise on Ventilation*, gives the quantities that will pass "supposing a mine to have such shafts and airways that when there are five equal splits of air the shaft resistances amount to one-half of the resistances offered by the mine . . . if before splitting the air at all we had a

Divisions of the current		Relatively.		
		s.	a.	$s\left(\frac{1}{a}\right)^s = u$.
		1.	2.	3.
1	Shafts.....	1	10	.001
	Mine.....	2	2	.25
				.251
2	Shafts.....	1	10	.001
	Mine.....	2	4	.03125
				.03225
3	Shafts.....	1	10	.001
	Mine.....	2	6	.009259
				.010259
4	Shafts.....	1	10	.001
	Mine.....	2	8	.00390625
				.00490625
5	Shafts.....	1	10	.001
	Mine.....	2	10	.002
				.003
6	Shafts.....	1	10	.001
	Mine.....	2	12	.0011574
				.0021574
10	Shafts.....	1	10	.001
	Mine.....	2	20	.00025
				.00125

Actual.			
u.	s.	a.	$q = \sqrt[3]{\frac{u}{k\,s}} \times a$
4.	5.	6.	7.
260.4	12,000	100	10,000
65100.	24,000	20	10,000
65360.4			
2026.7	12,000	100	19,817⅞
63333.7	24,000	40	19,817⅞
65360.4			
6370.4	12,000	100	29,030
58990.	24,000	60	29,030
65360.4			
13322.5	12,000	100	37,123
52037.9	24,000	80	37,123
65360.4			
21786.8	12.000	100	43,737
43573.6	24,000	100	43,737
65360.4			
30295 9	12,000	100	48,818
35064.5	24,000	120	48,818
65360.4			
52288.3	12,000	100	58,558
13072.1	24,000	200	58,558
65360.4			

ventilation of 10,000 cubic feet of air per minute," with the same ventilating pressure in force (see page 59, fourth edition). As the figures are different from those obtained above, we have brought them into a tabular form, and worked out the pressure (p) from the formula $\frac{k s v^2}{a}$ (see page 62).

It may be submitted that had Mr. Atkinson's quantities been correct, the pressure (p) should have been the same all the way down in the table; but it will be seen that the results are slightly different.

42. Again we have brought Mr. Atkinson's figures of page 60, fourth edition, into a tabular form and applied the rules $u=q\ p=vap$ to ascertain the power, and find the results are not quite the same in each case, though the difference is not very much, as will be seen from the last column of the table on page 63.

42[a]. A number of uneven splits subject to common pressure may be converted to one typical road that will offer the same

resistance in passing the same quantity of air, in the following manner:

Let r=the sum of the separate results for each split of—

$$\frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s}{a}}}$$

Let a'=the area of the new typical road,
" s'=rubbing surface of ditto, then

$$\frac{\left(\frac{1}{r}\right)^2 \times a'}{\left(\frac{1}{a'}\right)^2} = s'$$

EXAMPLE:—Reduce the three uneven splits below to one road 6 ft. square that will offer the same resistance with the same quantity, or pass an equal quantity with the same pressure.

	a.	s.	$\frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s}{a}}}$
1	30	59400	.674201
2	36	57600	.900009
3	35	72000	.771678
			2.345888

Divisions of the current.		s.	a.	q, as per Mr. Atkinson.	$p=\frac{ksv^2}{a}$
1	Shafts.	12,000	100	10,000	.02604
	Mine..	24,000	20	10,000	6.51
					6.53604
2	Shafts.	12,000	100	27,892	.20258
	Mine..	24,000	40	27,892	6.33067
					6.53325
3	Shafts.	12,000	100	49,449	.63673
	Mine..	24,000	60	49,449	5.89566
					6.53239
4	Shafts.	12,000	100	71,527	1.33223
	Mine..	24,000	80	71,527	5.20407
					6.53630
5	Shafts.	12,000	100	90,789	2.14638
	Mine..	24,000	100	90,789	4.29277
					6.43915
6	Shafts.	12,000	100	107,800	3.02607
	Mine..	24,000	120	107,800	3.50236
					6.52843
10	Shafts.	12,000	100	141,710	5.22928
	Mine..	24,000	200	141,710	1.30732
					6.53660

Divisions of the air current.		s.	a.	q, as per Mr. Atkinson.	$p=\frac{ksv^2}{a}$	$u=qp=vap$
1	Shafts.	12,000	100	10,000	.026	260.4
	Mine..	24,000	20	10,000	6.51	65100.
						65360.4
2	Shafts.	12,000	100	19,813	.1022	2025.31
	Mine..	24,000	40	19,813	3.1940	63291.
						65316.31
3	Shafts.	12,000	100	29,022	.2193	6365.
	Mine..	24,000	60	29,022	2.0308	58938.
						65303.
4	Shafts.	12,000	100	37,121	.3588	13319.
	Mine..	24,000	80	37,121	1.4016	52028.
						65347.
5	Shafts.	12,000	100	43,736	.4981	21785.
	Mine..	24,000	100	43,736	.9962	43570.
						65355.
6	Shafts.	12,000	100	48,797	.6200	30254.
	Mine..	24,000	120	48,797	.7176	35017.
						65271.
10	Shafts.	12,000	100	58,556	.89286	52282.
	Mine..	24,000	200	58,556	.22321	13070.
						53526.

$$\text{Then } \frac{\left(\frac{1}{2.34588}\right)^2 \times 36'}{\left(\frac{1}{36}\right)^2} = 8478\ s.$$

or $\frac{8478}{24} = 344\frac{11}{12}$; thus, a road 6 ft. square of this length or having a rubbing surface of 8478, will be equal to the three divided roads above.

Another example may be given to illustrate this rule. There are five unequal splits subject to one common pressure, with dimensions as below; find the value of s for a road 6 ft. square to give a resistance equal to that of all the splits together:

No.	Size.	Length.	$\frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s}{a}}}$
	ft. ft.		
1	8 × 3	1500	.6472313
2	5 × 5	1300	.7752171
3	4 × 5	1200	.6085806
4	6 × 6	1000	1.3942729
5	5 × 5	1300	.7752171
			4.2005190

Then $\dfrac{\left(\dfrac{1}{4.200519}\right)^2 \times 36'}{\left(\dfrac{1}{36}\right)^2} = 2644.24\ s.,$ the answer.

TO FIND THE QUANTITY THAT WILL RESULT FROM THE APPLICATION OF A GIVEN PRESSURE OR POWER IN A MINE HAVING UNEQUAL SPLITS, &c.

43. If there are a number of equal or unequal splits in a mine, all subject to one common pressure, the quantities that will pass in each split are in proportion to this formula:

$$\frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s}{a}}},$$

or finding p for an equal quantity passing in each split, the quantities in each split will be in proportion to $\frac{1}{\sqrt{p}}$.

44. The relative pressures or powers to pass the same quantity of air through aircourses of different areas and

rubbing surfaces may be found by $\frac{s\left(\frac{1}{a}\right)^2}{a}$ or $s\left(\frac{1}{a}\right)^3$ which formulæ we have used in obtaining the figures contained in the third column of each of the tables on pages 50, 51, and 58, 59.

45. When the aircourses are of the same area and perimeter, and the pressure is the same, the quantities are in proportion to the reciprocal of the square root of the length $= \frac{1}{\sqrt{l.}}$

46. The water-gauge due to friction is 9 in. The downcast is 10 ft. in diameter and 70 fathoms deep, the upcast is 9 ft. diameter and 70 fathoms deep. The aircourses underground are as follows.

One	900	yards long	6 ft. × 5 ft.
"	800	"	6 ft. × 6 ft.
"	1,000	"	7 ft. × 5 ft.

Find the quantity of air passing, applying Mr. Atkinson's co-efficient of friction throughout—

.9 in. × 5.2 = 4.68 lbs. pressure.

In this case we proceed to find the pressure necessary for passing 40,000, which altogether amounts to 8.8561 lbs., then as $\sqrt{8.8561} : 40,000 :: \sqrt{4.68} =$ 29,077, as worked out in the table (page 69), the formula at the head of each column explains where necessary the manner of proceeding; it has been assumed that the splits are subject to one common pressure.

47. The next table (page 70) is given by way of exercise for the student—the question being, What quantity of air will pass through the mine with a total pressure of 8 lbs. per square foot, the current being divided as specified, Nos. 1 and 2 being the shafts, 3, 4, 5, and 6 splits, subject to the same pressure? It is not necessary here to explain how the figures in the first seven columns of this table have been obtained, but those of column 8 are on the assumption that 40,000 ft. of air pass through each division (any other quantity might have been assumed); column 9 is the the reciprocal of the square root of the pressure given

Divisions of the air currents.	a.	s.	Relative pressures $= \frac{\left(\frac{1}{a}\right)^2 \times s.}{a}$	Square root of relative pressures $= \sqrt{\frac{\left(\frac{1}{a}\right)^2 \times S'}{a}}$ or $\sqrt{S\left(\frac{1}{a}\right)^3}$	Reciprocal of the sq. root of relative pressures = relative quantities $= \frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s.}{a}}}$	Quantities in direct proportion to relative quantities.	p, for assumed quantity $= \frac{k\,s\,v^2}{a}$	p = in direct proport'n to figures in previous col.	$q = \sqrt{\frac{p\,a}{k\,s}}\,a$
Downcast.	78.54	13194 72				40,000	.9456	.4997	29,077
Upcast. . .	63.6174	11875 284				40,000	1.6014	.8462	29,077
1st airc'rse	30	59.400	2.1999956	1.4832382	.674201	11,496	6.3091	.3341	8,357
2d airc'rse	36	57,600	1.2345332	1.1110999	.900009	15,346			11,156
3d airc'rse	35	72,000	1.679296	1.2958768	.771678	13,158			9,564
					2.345888	40,000	8.8561	4.68	29,077

No.	Size.	Length.	Perimeter.	s.	a.	q.	$p = \frac{ksv^2}{a}$	$\frac{1}{\sqrt{p}}$	q.	p.	p in proportion to col. 11, total being 8 lbs.	Actual quantity for the total pressure of 8 lbs.	u.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.
1	8 × 8	900	32	28,800	64	40,000			40,000	3.814	2.147	30,012	64,436
2	7 × 7	900	28	25,200	49	40,000			40,000	7.437	4.187	30,012	125,660
3	8 × 3	1,500	22	33,000	24	40,000	82.88188	.1098424	7,558			5,671	9,448
4	5 × 5	1,300	20	26 000	25	40,000	57.77408	.1315629	9,053	2.959	1.666	6,792	11,315
5	4 × 5	1,200	18	21,600	20	40,000	93.74400	.1032828	7,107			5,332	8,883
6	6 × 6	1,000	24	24,000	36	40,000	17.86005	.2366237	16,282			12,217	20,354
								.5813118	40,000	14.210	8.000	30,012	240,096

in column 8. In column 10, we give the quantities that pass in each division when the total is 40,000; of course the two shafts (1 and 2) pass the total quantity of 40,000, and the quantity in each division underground is in direct proportion to the figures given in column 9. In column 11 it is seen that the total pressure required to pass 40,000 is 14.21 lbs., but as only 8 lbs. is the pressure in force, we proportion the figures in column 12 with those of 11, so that they amount to 8 lbs. and then we find if $\sqrt{14.21}$ give 40,000 that $\sqrt{8}$ will give 30,012, and that the quantities passing in each split 3, 4, 5, and 6 will be according to the figures given in column 13, and the total power (u) as per column 14, will be 240,096.

48. By way of exercise for the student it has been further assumed that another aircourse (No. 7) 5×5 and 1,300 ft. long be added to those enumerated in the previous paragraph, and that the power in force remains the same. With these conditions the quantity passing, it will

be seen, is only increased from 30,012 to 30,744, as per table on page 73.

In this case we have proportioned the quantities in each split by the figures in column 7; and in taking 30,012 as the total quantity of air passing we find the pressure, as per column 9, to be 7,442; this multiplied by the quantity gives 223,349 units; then we find if $\sqrt[3]{223349}$ give 30,012 that the $\sqrt[3]{240096}$ gives 30,744, and the quantity in each split is proportioned again according to the figures in column 7. The pressure, p, in column 11 may be obtained by proportioning it with the figures in columns 8, 9, and 10, or by working out directly from the quantity in column 10 by the formula—$p=\frac{k\,s\,v^2}{a}$, and u in column 12 is obtained by multiplying the figures in columns 10 and 11 together; and it will be seen that the total units in this column amount to 240,098, which is correct within 2 units in the previous table.

49. Suppose a mine to have two splits of air only, one offering five times as

No.	Size.	Length.	Perimeter.	s.	a.	$\frac{1}{\sqrt{\frac{\left(\frac{1}{a}\right)^2 \times s}{a}}}$	q.	p.	q.	p.	u.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1	8×8	900	32	28,800	64		30,012	2.147	30,744	2.2533	69,275
2	7×7	900	28	25,200	49		30,012	4.187	30,744	4.3933	135,068
3	8×3	1,500	22	33,000	24	.6473508	4,624		4.737		5,509
4	5×5	1,300	20	26,000	25	.7054475	5,539		5,674		6,599
5	4×5	1,200	18	21,600	20	.6085806	4,348	1.108	4,454	1.1630	5,180
6	6×6	1,000	24	24,000	36	1.3942729	9,962		10,205		11,868
7	5×5	1,300	20	26,000	25	.7054475	5,539		5,674		6,599
						4.0610993	30,012	7.442	30,744	7.8096	240,098

much resistance as the other, and that the ventilating pressure required to circulate the air through the shafts and undivided airways is one-twelfth of the whole ventilating pressure. With a total quantity of 100,000 feet passing per minute, and putting the rubbing surface of the shafts at 10,000 and area at 100, then the figures in the table below will show the relative rubbing surfaces, areas, quantities, and pressures meeting these conditions.

Divisions of the air.	*s.*	*a.*	*q.*	*p.*
Shafts.....	10,000	100	100,000	2.17
Mine.....	1,151,912	100	30,902	23.87
	230,388	100	69,098	
				26.04

50. If the pressure remain the same as stated in previous paragraph, and there are three splits offering resistances in the ratio of 3, 2, 1, then the relative quantities, rubbing surfaces, areas, and pressures will be according to the following table:

Divisions of the air.	*s.*	*a*	*q.*	*p.*
Shafts.....	10,000	100	148,869	4.81
Mine.....	691,150	100	37,623	21.23
	460,767	100	46,079	
	230,383	100	65,167	
				26.04

The examples given in this and the previous paragraph are to be found in another form at page 182 in the Transactions of the North of England Institute of Mining Engineers, Vol. VI.

51. If the downcast and upcast shafts of a colliery are each 180 fathoms deep and 12 ft. 5 in. diameter, and with one undivided aircourse in the mine having $a=36$ and $s=120,000$, the quantity of air circulating is 15,000 cubic feet per minute, what quantity will pass when there are 2, 3, 4, 5, and 6 equal splits, the pressure remaining the same? In the first place we find the total pressure required to pass 15,000 ft. of air with only one aircourse is 12.78954 lbs., then we find what the relative pressures are

Divisions of the current.		a.	s.	Relative pres'ures on a quantity of 15,000= $\frac{k s v^2}{a}$
No	1.	2.	3.	4.
1	Shafts..	121.087	84,240	
	Mine....	36	120,000	
2	Shafts..	121.087	84,240	.231669
	Mine....	72	120,000	1.569734
				1.801403
3	Shafts..	121.087	84,240	.231669
	Mine....	108	120,000	.465106
				.696775
4	Shafts..	121.087	84,240	.231669
	Mine....	144	120,000	.196217
				.427886
5	Shafts..	121.087	84,240	.231669
	Mine....	180	120,000	.100463
				.332132
6	Shafts..	121.087	84,240	.231669
	Mine....	216	120,000	.058138
				.289807

p.	*q.*	*u.*
5.	6.	7.
.231669	15,000	3,475
12.557871	15,000	188,368
12.789540		191,843
1.644796	39,968	
11.144744	39,968	
12.789540		511,172
4.252363	64,265	
8.537177	64,265	
12.789540		821,920
6.924602	82,008	
5.864938	82,008	
12.789540		1,048,845
8.920971	93,082	
3.868569	93,082	
12.789540		1,190,476
10.223839	99,647	
2.565701	99,647	
12 789540		1,274,439

on 15,000 in the case of all the splits, as per column 4; the pressure in column 5 is then apportioned directly according to the figures in column 4; and from the pressure in column 5 we get the quantity in column 6 by the rule—$\sqrt{\frac{p\ a}{k\ s}} \times a$ and u is got by multiplying p and q together.

Supposing it be required to know what quantity will pass with the power (u) remaining the same, we find by the table that this amounts to 191,843 units when the air is passing round the mine in one current, then by the table we see that with the same pressure there are 39,968 feet of air passing with two splits, and that the power (u) amounts to 511,-172, then we say

As $\sqrt[3]{511172} : 39968 :: \sqrt[3]{191843} : 28666$, the quantity of air that will pass when there are two equal splits, and the power remains the same, or we work out the results in the case of all the splits as follows:

$$\text{With 2 splits} = \frac{\sqrt[3]{191843} \times 39968}{\sqrt[3]{511172}} = 28666$$

$$\text{With 3 splits} = \frac{\sqrt[3]{191843} \times 64265}{\sqrt[3]{821920}} = 39347$$

$$\text{With 4 splits} = \frac{\sqrt[3]{191843} \times 82008}{\sqrt[3]{1048845}} = 46291$$

$$\text{With 5 splits} = \frac{\sqrt[3]{191843} \times 93082}{\sqrt[3]{1190476}} = 50370$$

$$\text{With 6 splits} = \frac{\sqrt[3]{191843} \times 99647}{\sqrt[3]{1274439}} = 52617$$

ASCENSIONAL VENTILATION.

52. By ascensional ventilation is meant the art of conducting the air underground so that it shall in the first place go directly to the lowest part of the workings and afterwards rise as it returns to the bottom of the upcast shaft. The intake generally being colder than the return, by this system return air is made to ascend and not descend. There is a loss of power in conducting return air downwards to the upcast, and this is a practice that should be avoided as much as possible.

53. The rules and tables referring to the friction of air and to the different quantities that will circulate with certain pressures, as given in the previous chapters, apply only to horizontal channels and not to dip and rise roads; for in practice it is found, whilst the quantities of air that will pass in different splits

in the same horizontal plane preserve the same proportion whatever the ventilating pressure may be, such is not the case with dip and rise plits.

54. The reason of this is that there is a difference between the density of the intake and return air due to change of temperature, the mixture of watery vapor, the emission of gases, &c., and as the return air of any current is generally less dense than the intake (on account of the gases emitted being usually lighter than common air, &c.) there is mostly a natural influence at work in favor of the intake current passing to the dip, and returning by an ascending route, and against the air going first to the rise and returning by a descending road. Supposing a dip and rise split to be subject to one common ventilating pressure, in the case of the dip split there is to be added the pressure due to natural influences, in the case of the rise split the pressure due to natural influences is to be deducted from the general ventilating pressure, and thus it happens if there be

a long split and a short one, both level, in order to pass equal quantities of air in each it will be necessary to put a regulator in the short one; and on reducing or increasing the ventilating pressure the quantities will still be equal, but if the long one is a dip split and the short one a level one, on reducing the total quantity of air the long split will get a greater proportion than originally. On the other hand, if the long split is a rise one and the short split a horizontal one, on reducing the total quantity of air the long split passes less and the short one more than the original share. This fact, so repeatedly proved in practice, clearly shows the value of the principle of ascensional ventilation and the mistake in carrying return air down the bank. If, however, the returns were charged with gases heavier than common air to such an extent as to render them more dense than the intake air, the opposite results would take place on reducing or increasing the general ventilating pressure in the case of dip and rise splits. This,

however, is an exceptional case, for, as said before, the return air of mines is generally less dense in consequence of being usually higher in temperature, and impregnated with the lighter gases; and it is therefore, speaking generally, wrong in principle to bring return air down the hill. The descent of return air in places which give off fire damp has been, and is likely to be, the cause of serious explosions.

55. In colleries giving off fire damp it is well to have the return aircourse on the upper side of the workings; by this means the gas will be naturally drained away by gravity from the goaves or where workmen are employed.

56. If the ascensional principle of ventilation be carried out, the exudation of carburetted hydrogen in a mine will have the effect of increasing the ventilation. The light specific gravity of the fire damp, as compared with that of air, will be equal to an additional ventilating pressure. This principle appears to be well understood in Belgium and in West-

phalia, particularly so in the last-mentioned coalfield, where, according to the experience of the writer, it is the prevailing system.

57. In furnace ventilation the best current of air is produced by having the furnace placed on the dip side of the underground workings, because in that case a longer motive column or ventilating pressure is obtained; but in steep-lying seams the advantage derived by the natural ascendancy of warm air and light gas is not only lost, but an additional pressure equivalent to this advantage is required to bring the light air down to the bottom of the upcast. Hence, ventilating fans made to exhaust the air from a shaft on the rise side of the workings are both in point of economy and safety better for ventilating steep seams than furnaces placed on the dip side.

58. If we suppose the rise workings to reach the vertical height of 50 fathoms, and the temperature of the intake be 55 degs. and return 85 degs., there will be a natural pressure due to tem-

perature alone of 1 lb. per square foot, or one-fifth of an inch of water gauge in favor of mechanical ventilation with upcast shaft at the rise of the workings, and against furnace ventilation with the upcast at the dip, in addition to the extra resistance consequent on the increased length of aircourse and upcast. In order to make this plain to the student, we take from the table of the weight of air given under paragraph 6 the weight of a foot at 55 degs. =.0773515, and multiply this by 300=23.20545, and deduct the weight at 85 degs. =.0730858 multiplied by 300=21.192574, which gives a difference of 1.01 lb.

59. The average temperature of a furnace upcast may generally be taken at 100 degs. (at least) more than that of the mine, and consequently the increased pressure obtained at the bottom of the upcast by this increased length of heated air column will overcome any local pressure in the mine and compel the air to travel down-hill from the rise workings

to the furnace, but this will be at the expense of additional fuel.

60. It has been stated that the gases emitted from mines are generally such as to render the return air lighter than the intake. This, however, depends on the specific gravity of the gas. The table following shows the specific gravity of the various gases met with in mines and the relative altitude they usually assume:

	S.G.
Hydrogen	0.069
Carburetted hydrogen	0.550
Aqueous vapor	0.620
Nitrogen and Miasma	0.976
Olefiant	0.980
Air	1.000
Oxygen	1.100
Sulphuretted hydrogen	1.190
Carbonic acid	1.520
Sulphurous acid	2.120

Those gases which are lighter than air have an influence in favor of the ascensional principle of ventilation; those which are heavier will act prejudicially to it.

VELOCITY OF AIR.

A velocity of 6 in. per second or 30 ft. per minute is enough to deflect the flame of a candle, and 3 ft. per second is sufficient to remove and render harmless the ordinary discharges of fire damp. A return aircourse 7 ft. square passing 30,000 cubic feet of air per minute gives a velocity of about 10 ft. per second. In many of the furnace pits of the North of England the air travels at a velocity as high as 30 ft. per second. It is not always practicable, however desirable, to reduce the velocity in returns or upcast shafts to a minimum, but it is very important that the air in the working parts of a mine should not travel at less than say 2 ft. per second, or more than 7 ft. The medium between these would be the best average velocity; but a very much greater velocity than this is attained in some collieries.

62. There are several reasons why air should not travel at a high velocity. One is because, if it be very much surcharged with fire damp, enough to render it inflammable, there is a danger of some of the commonly used lamps exploding. Another reason is that the pressure required to overcome the friction is according to the square of the velocity, and the power according to its cube. The following table shows the relative pressures and powers required to move the air through the same aircourse at the velocities stated:

Velocity in ft. per second.	Relative pressures.	Relative powers.
3	1.	1.
4	1.77	2.37
5	2.77	4.63
6	4.	8.
7	5.44	12.70
8	7.11	18.96
9	9.	27.
10	11.11	37.03
12	16.	64.
14	21.77	101.63
16	28.44	151.70

Thus we see there is 16 times the pressure and 64 times the power required to pass the air through the same channel, at a velocity of 12 ft. per second that is necessary at 3 ft. per second. Thirdly, when air travels too rapidly it is disagreeable to the workmen and all who have to move in it; and it is difficult to prevent the light from being blown out.

63. Each split should have a current of 8,000 or 10,000 cubic feet per minute and the latter quantity at a velocity of 5 ft. per second would require an area of 33 square feet.

An inflammable mixture of pit gas and air, moving at the rate of 8 ft. per second will explode most of the ordinary safety (?) lamps.

THE CO-EFFICIENT OF FRICTION.

64. Throughout this treatise we have used the co-efficient of Mr. Atkinson, namely, .0000000217 lb. for each foot of rubbing surface, and a velocity of 1 ft. per minute. From this we find that $v=6788$

$$\sqrt{\frac{pa}{s}}, \text{ because } \sqrt{\frac{1}{.0000000217}}=6788.$$

65. Mr. D. K. Clark, in his most excellent book, *Rules, Tables and Data for Mechanical Engineers*, gives the following formula for the "flow of air through passages of any form of section" (substituting the notation used throughout these papers it is):

$$v=796\sqrt{\frac{wa}{s}}$$

and to bring this into the same terms as above:

$$\frac{796 \times 60}{\sqrt{5.2}} = 20{,}944,$$

therefore:

$$v = 20{,}944 \sqrt{\frac{pa}{s}}$$

66. M. Devillez, in his *Ventilation des Mines*, uses a co-efficient which is equal to .00000000951 lb. for each foot of rubbing surface and a velocity of 1 ft. per minute, now as:

$$\sqrt{\frac{1}{.00000000951}} = 10{,}253 \; v = 10{,}253 \sqrt{\frac{pa}{s}}$$

67. Recapitulating, we see that the velocity is found according to these three authorities as below:

Per Atkinson, $v = 6{,}788 \sqrt{\frac{pa}{s}}$

Per Devillez, $v = 10{,}253 \sqrt{\frac{pa}{s}}$

Per Clark, $v = 20{,}944 \sqrt{\frac{pa}{s}}$

68. The writer is inclined to think that Mr. Clark's formula is deduced from experiments with passages having

smoother sides than those of underground roads generally, and consequently the friction is not so great; he has confidence in the result obtained by M. Devillez, but thinks until further experiments have been made it would be sufficiently near, as an average for underground passages, to use $10{,}000\sqrt{\frac{pa}{s}}$. This would be equal to .00000001 pound per square foot of rubbing surface, or $\frac{1}{100{,}000{,}000}$ for a velocity of one foot per minute, or .01 lb. or $\frac{1}{100}$ for a velocity of 1,000 ft. per minute, and these are factors that could be both easily remembered and used in calculation.

NOTE.

69. In the preceding pages calculations have been gone into to show the quantities of air that will circulate under certain conditions; it is necessary to state that these conditions never exist practically; for example, "equal splitting," as has been explained under paragraph 31, cannot very well exist in a practical sense; then again in considering "unequal splitting," it has been assumed that the splits are all subject to one pressure; this can only be the case when all the splits divide from the main current at one point, and reunite again in the return at one point, which will not be found to be the case practically. It has already been pointed out in the earlier pages that one of the conditions—assumed to exist — is wanting in the case of dip and rise splits. Another condition affecting the consideration of

the quantities that will pass with various powers or pressures is the co-efficient of friction; in the calculations it has been assumed that one co-efficient applies throughout the whole ramifications of the mine, from the entrance of the air at the mouth of the downcast till it escapes at the top of the upcast; but from experiment it has been found that the co-efficient varies with the nature of the rubbing surface; that in an arched tunnel or brick-lined shaft, for example, it is not nearly so much as for the ordinary channels of a mine. It has likewise been assumed that all the air which enters the mine passes completely through it, but this is not the case practically; air escapes at doors, stoppings, crossings, brattice, and through goaves, &c., and this to a very large extent in some collieries.

70. The amount of this fugitive air, if it may be so called, is not always a criterion of the ability displayed in carrying out the ventilation; in collieries having good means of producing air, and with

limited workings, it is more permissible than in extensive collieries which require all the air in-bye that can be obtained; in such cases as the latter care must be taken to prevent the escape of air by taking the short route to the return, instead of passing through the working places.

71. All open places in a coal mine, whether in work or not, should have air passed through them, and in no case should old workings be shut up with air-tight stoppings; such a practice is very likely to lead to some casualty through places of this kind becoming dangerous magazines of gas.

72. It is hoped the calculations that have been gone into may be of some assistance to students in undertanding the question. The principal matter of this essay was worked out some twelve months ago, when the writer intended to consider the subject further; since then, however, his engagements have prevented him from devoting the necessary time to it, and for this reason certain experiments on the subject cannot at present be utilized.

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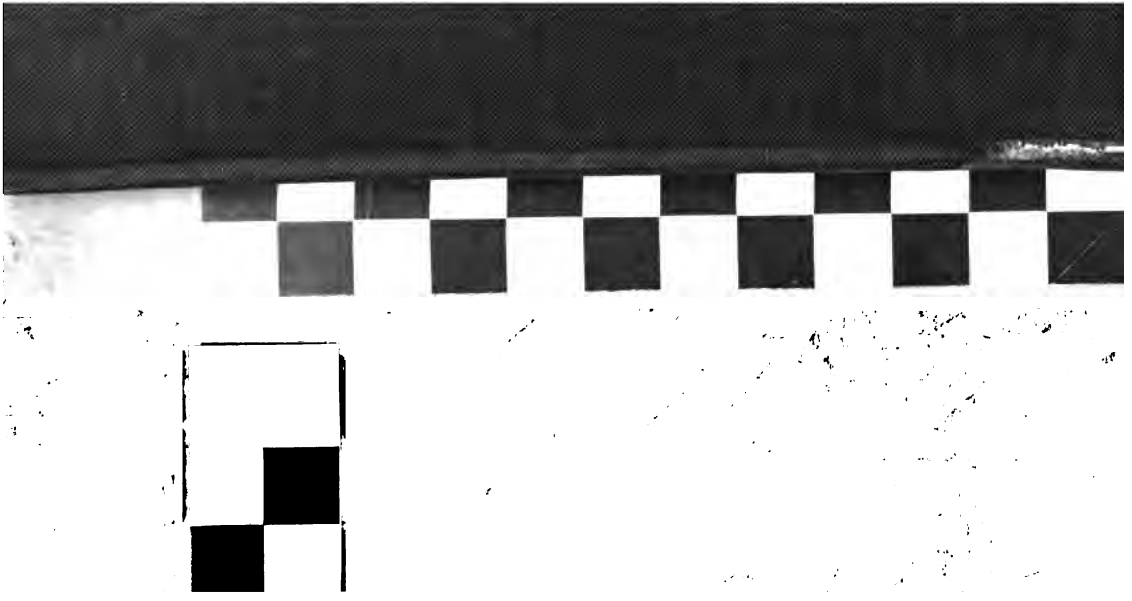
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